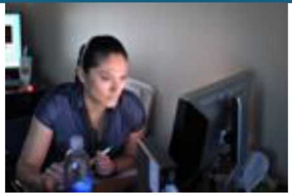
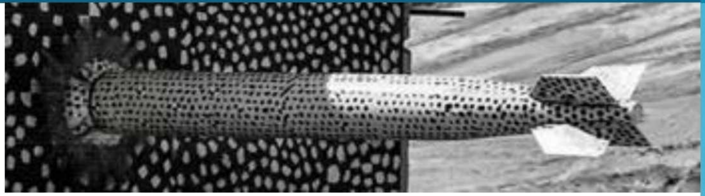
SAND2020-1639PE

MEETING 100% CARBON-FREE ENERGY MANDATES – A NEW MEXICO CASE STUDY





PRESENTED BY

Dr. Tu Nguyen

Nevada PUC – Energy Storage Workshop 2020

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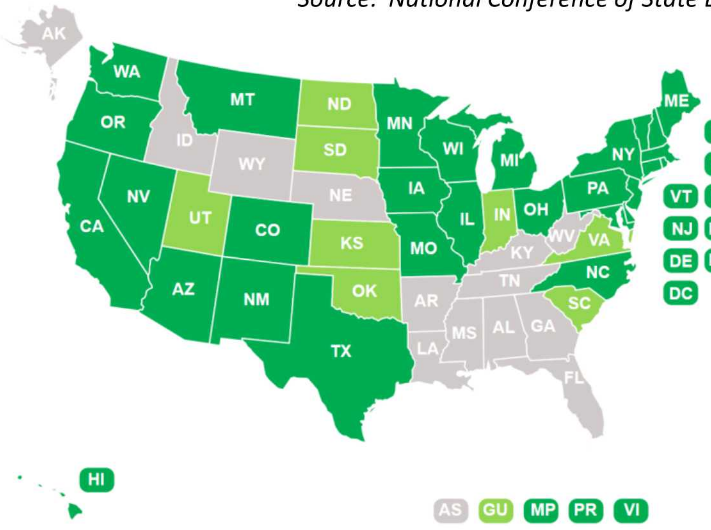
OUTLINES

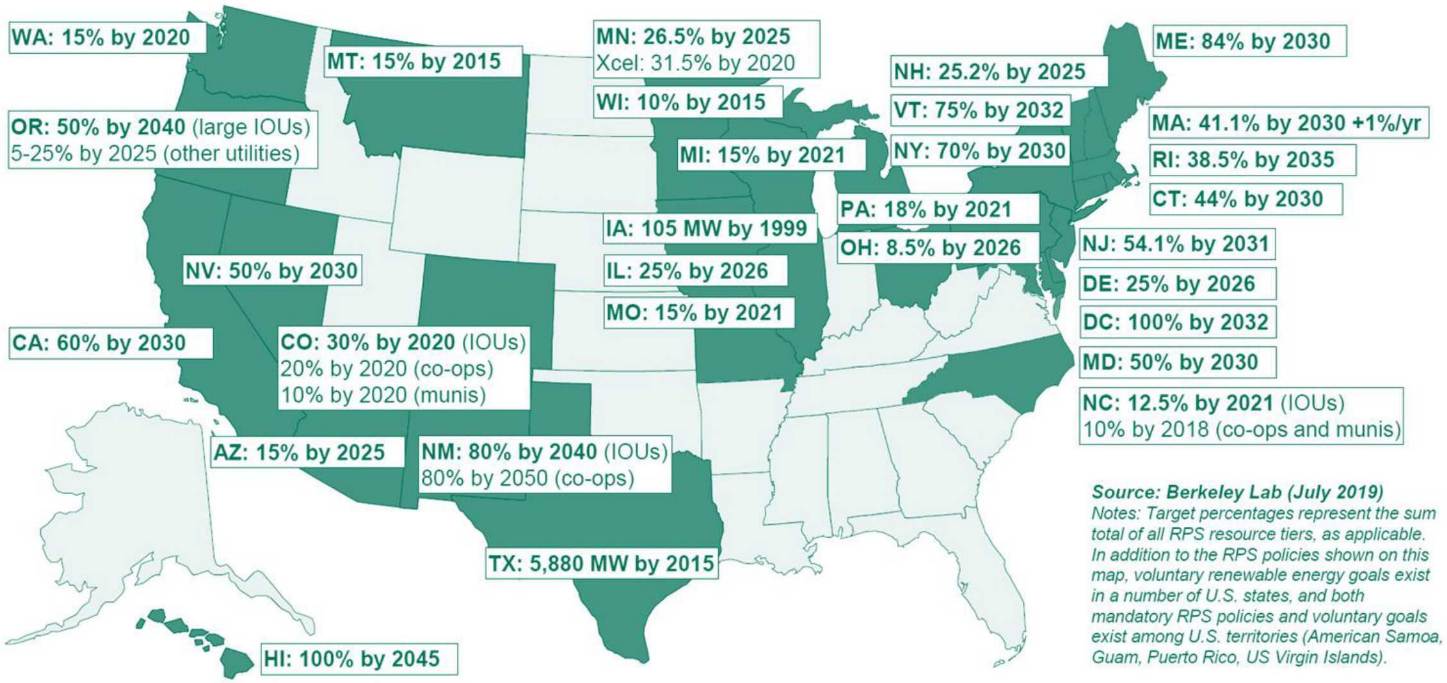
- Overview of Renewable Portfolio Standards (RPS).
- Technical challenges for 100% renewable grid.
- The need for energy storage.
- Integrated Resource Planning (IRP) for 100% renewable grid.
- New Mexico case study
- Future work

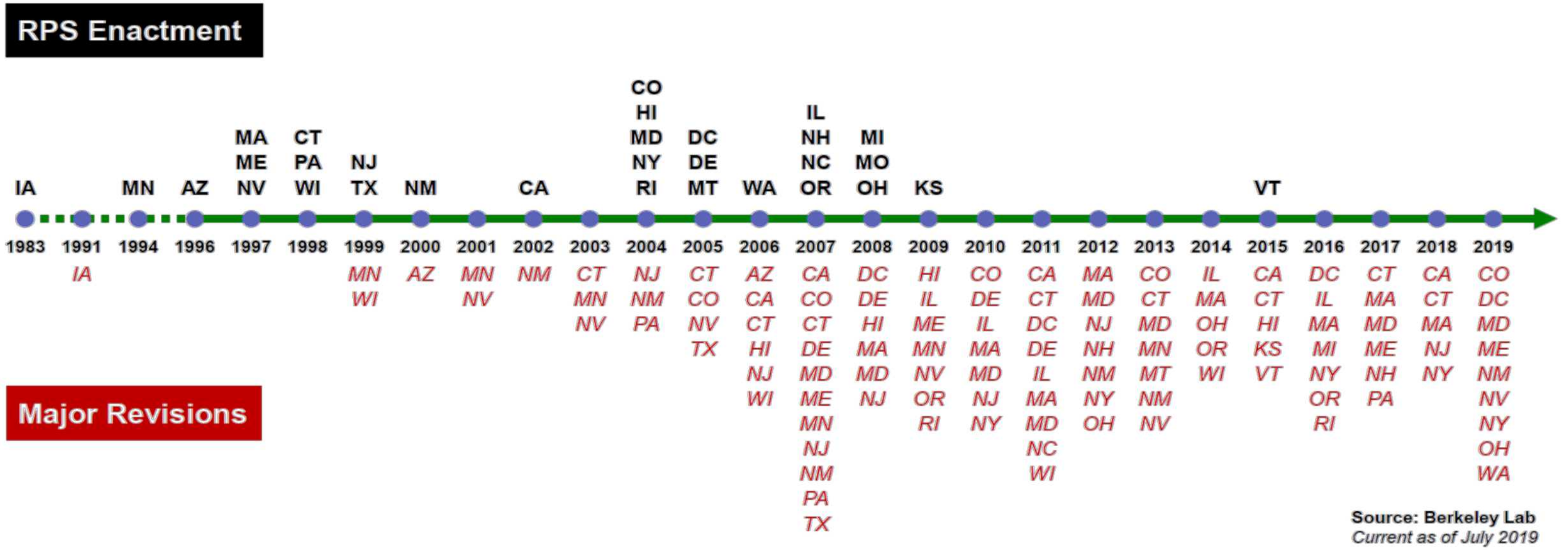
OVERVIEW OF RPSs IN THE US

States and territories with Renewable Portfolio Standards | States and territories with a voluntary renewable energy standard or target | States and territories with no standard or target

Source: National Conference of State Legislatures



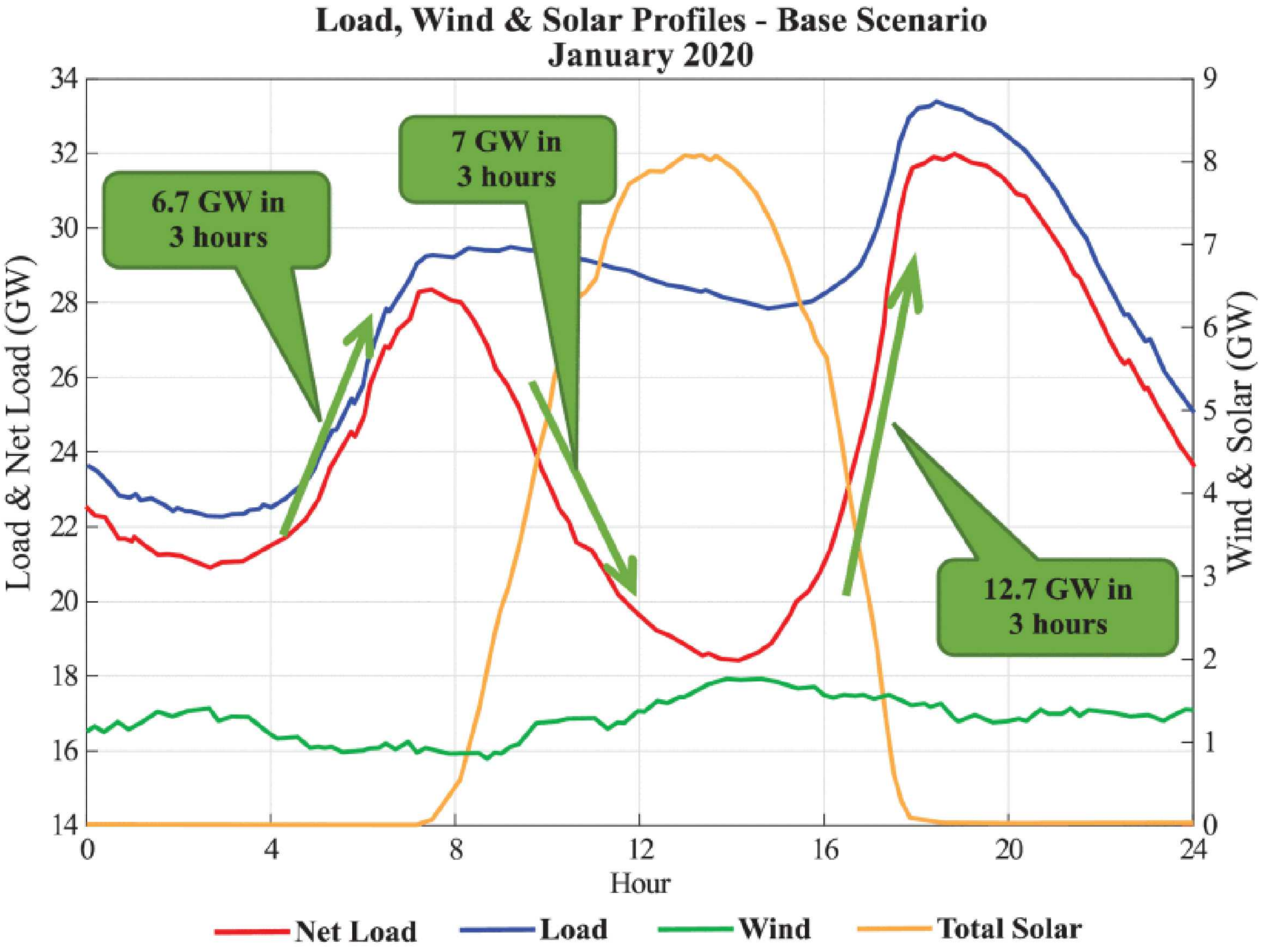




10 states increased their RPS targets:

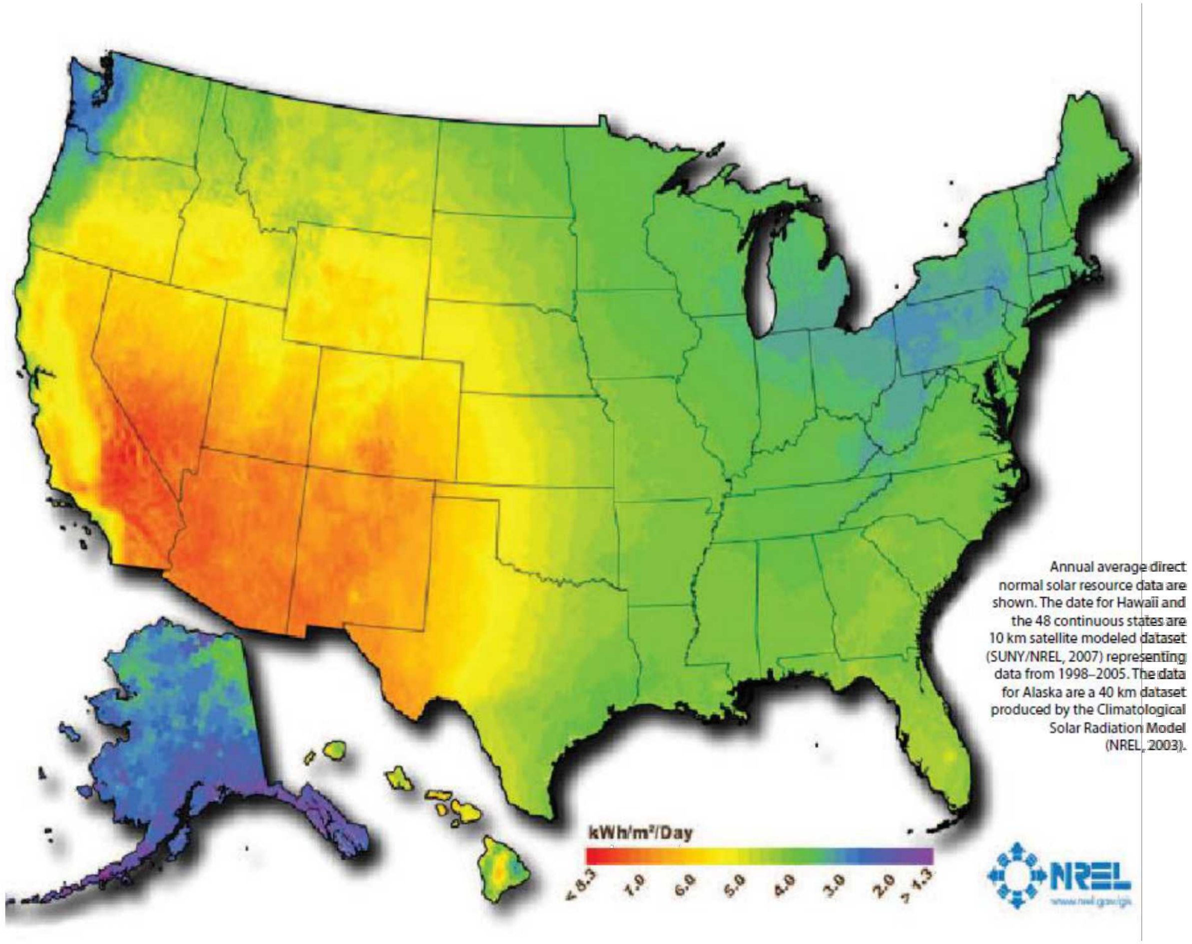
- **CA:** 60% by 2030 (and 100% zero-carbon by 2045)
- **CT:** 40% Class I by 2030
- **DC:** 100% by 2032, with 10% solar by 2041
- **MA:** Annual increase of 2% of sales/year over 2020-2029
- **MD:** 50% Tier 1 by 2030, incl. 14.5% solar + ~9.5% OSW
- **ME:** 50% Class I by 2030
- **NJ:** 50% Tier 1 by 2030
- **NM:** 80% by 2040 (and 100% zero-carbon by 2045)
- **NV:** 50% by 2030
- **NY:** 70% by 2030 (and 100% zero-carbon by 2040)

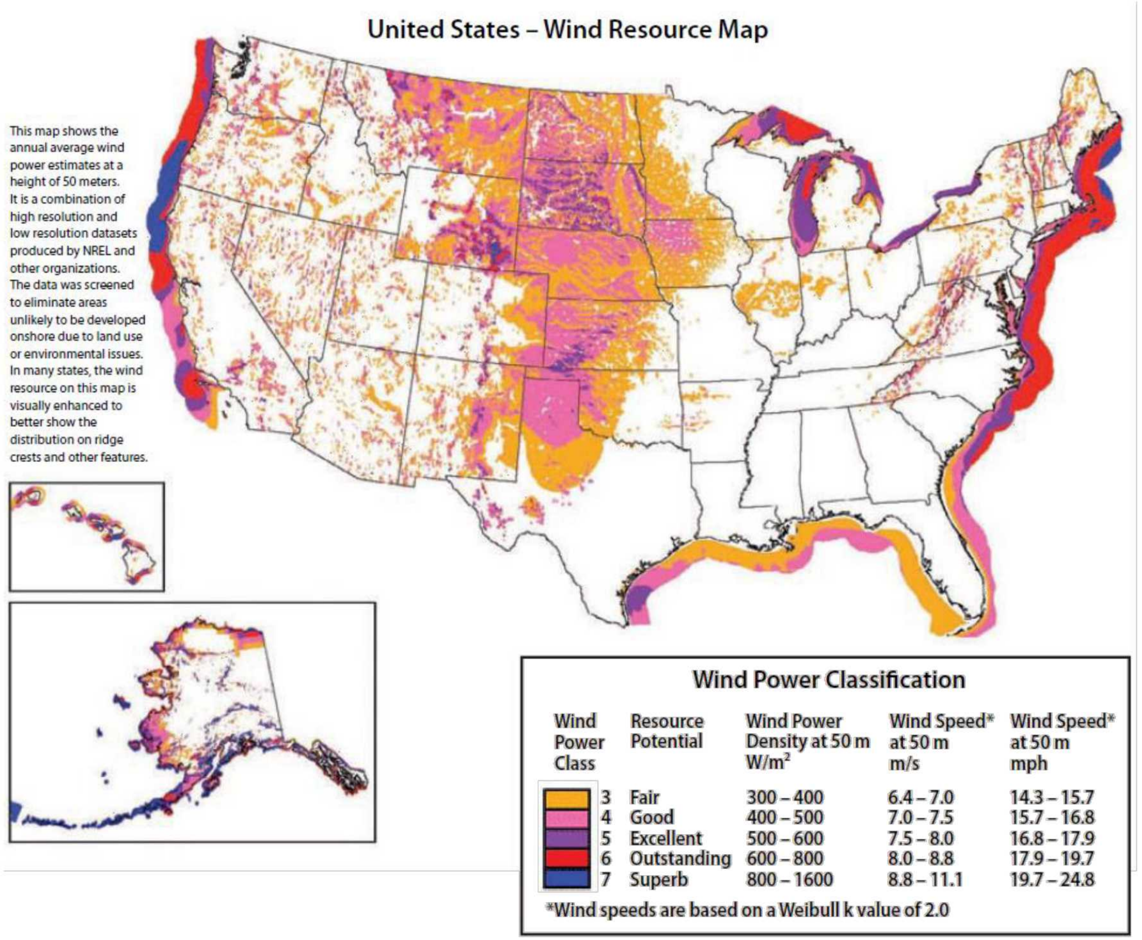
CHALLENGES FOR 100% RENEWABLE GRID – HIGH VARIABILITY AND UNCERTAINTY



- Solar PV creates larger ramps since large amount of energy is produced only during daytime, which is not coincident with the peak load.
- Wind generation tends to be larger during nighttime, which also create ramps.
- Renewable plants are often oversized to deal with weather variability and uncertainty.

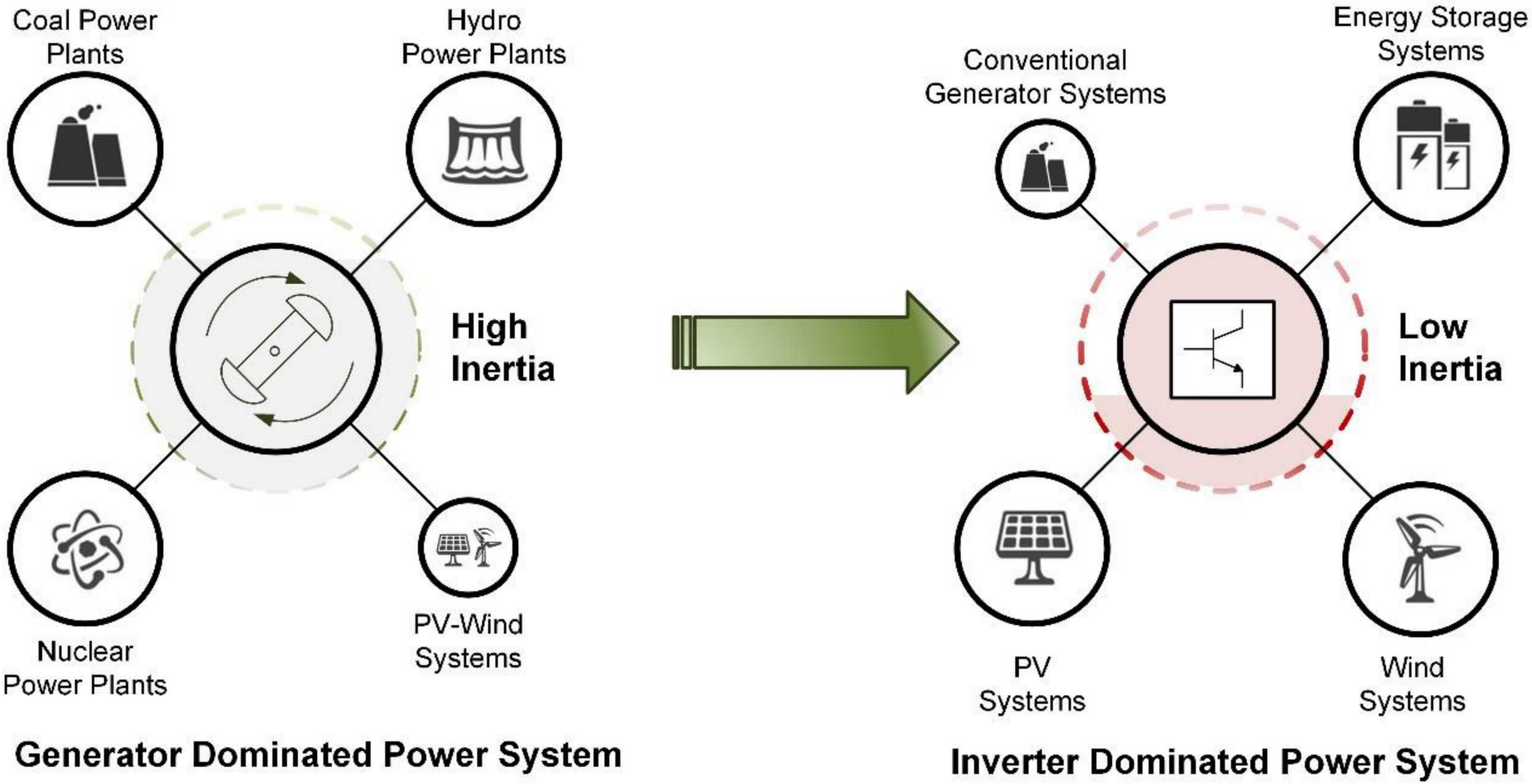
CHALLENGES FOR 100% RENEWABLE GRID – TRANSMISSION ISSUE





- Most attractive resources for wind and solar are located far from load center. Therefore, exploiting these resources requires enormous transmission expansion.

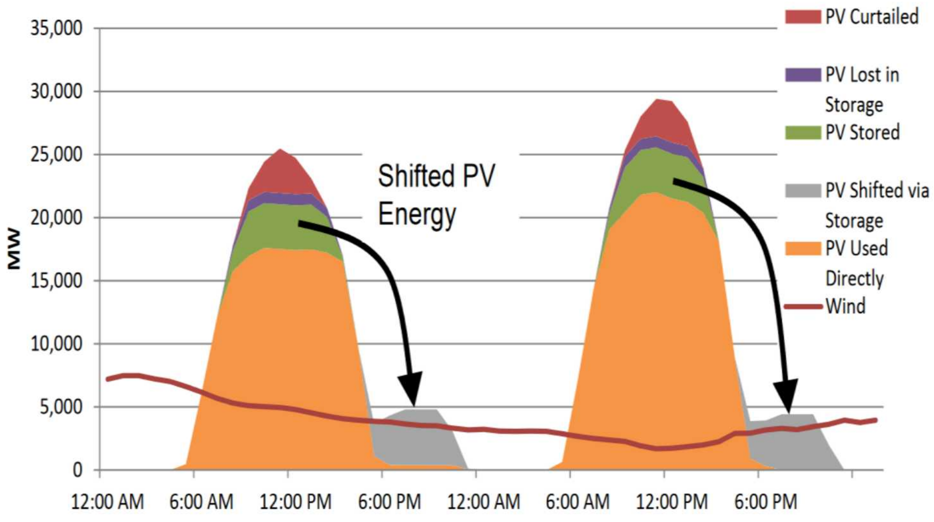
CHALLENGES FOR 100% RENEWABLE GRID – ZERO INERTIA



Source: U. Tamrakar, D. Shrestha, M. Maharjan, B. Bhattarai, T. Hansen, and R. Tonkoski, "Virtual Inertia: Current Trends and Future Directions," Applied Sciences, vol. 7, no. 7, p. 654, Jun. 2017.

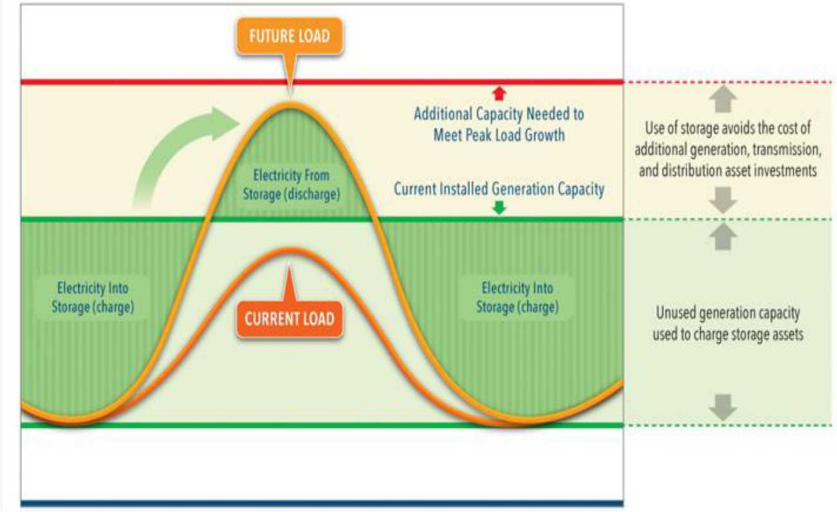
THE NEED FOR ENERGY STORAGE

Example - Ramp support + Peak Shaving



Source: NREL

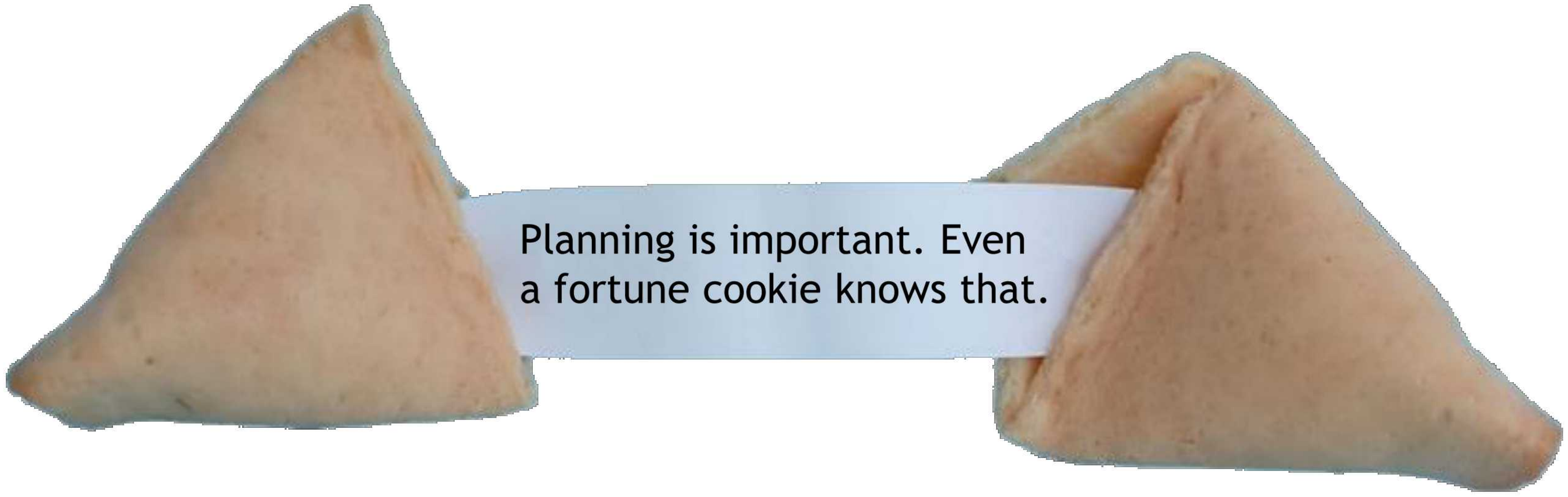
Example – T&D Deferral



Source: NRStor Inc

- Renewable integration: smoothing, firming, time shift.
- Ancillary services: capacity, regulation, ramp support.
- Virtual inertia.
- T&D upgrade deferral.
- Behind-the-meter applications: back-up power, power quality, TOU management, demand charge reduction.

INTEGRATED RESOURCE PLANNING FOR 100% RENEWABLE GRID



- The IRPs must consider RPS targets.
- Long-term requirements must consider technical challenges created by renewable energy.
- Energy storage must be included together other resources

SIZING PV, WIND, AND STORAGE

Image Credit: DNV GL

- We develop an optimization framework for determining the smallest resource sizes required to balance the demand with renewable resources and energy storage.
- This optimization considers multiple types and locations of renewable resources, and also allow energy trading with external providers.

METHODOLOGY AND FORMULATION

Methodology

A mathematical optimization problem is formulated the objective of minimizing energy resource sizes while ensuring that the utility's demand is met at all times. The constraints of this problem include:

- **Storage constraints:** state of charge constraints.
- **Power balance constraint:** load must be met.
- **Curtailment constraint:** renewable curtailment must be limited.
- **Interconnection constraint:** the energy exchanged with other regions must be limited.

Formulation

Objective function:

$$\underset{\substack{\bar{s},\bar{p}^{\mathrm{s}},\bar{p}^{\mathrm{w}},\bar{p}^{\mathrm{pv}},\\ p^{\mathrm{c}},p^{\mathrm{d}},p^{\mathrm{curt}},p^{\mathrm{trade}}}}{\text{minimize}} \quad J(\bar{s},\bar{p}^{\mathrm{s}},\bar{p}^{\mathrm{w}},\bar{p}^{\mathrm{pv}},p^{\mathrm{curt}},p^{\mathrm{trade}})$$

$$J(\bar{s},\bar{p}^{\mathrm{s}},\bar{p}^{\mathrm{w}},\bar{p}^{\mathrm{pv}},\mathbf{p}^{\mathrm{trade}}) := w^{\mathrm{c}}\bar{s} + w^{\mathrm{p}}\bar{p}^{\mathrm{s}} + w^{\mathrm{w}}\sum_{i=1}^{n_{\mathrm{w}}}\bar{p}_i^{\mathrm{w}} + w^{\mathrm{pv}}\sum_{i=1}^{n_{\mathrm{pv}}}\bar{p}_i^{\mathrm{pv}} + \sum_{k=0}^{K-1} w_k^{\mathrm{curt}}p_k^{\mathrm{curt}} + \sum_{k=0}^{K-1} w_k^{\mathrm{trade}}p_k^{\mathrm{trade}}$$

Storage and renewable constraints:

$$\underline{\delta}\bar{s} \le s_k \le (1-\bar{\delta})\bar{s}$$
$$s_{k+1} = \eta^{\mathrm{s}}s_k + \eta^{\mathrm{c}}p_k^{\mathrm{c}}\tau - p_k^{\mathrm{d}}\tau$$
$$s_0 = \gamma\bar{s}$$
$$s_K = \gamma\bar{s}$$

$$0 \le p_{k,i}^{\mathrm{w}} \le \bar{p}_i^{\mathrm{w}}$$
$$0 \le p_{k,i}^{\mathrm{pv}} \le \bar{p}_i^{\mathrm{pv}}$$
$$0 \le p_k^{\mathrm{c}} \le \bar{p}^{\mathrm{s}}$$
$$0 \le p_k^{\mathrm{d}} \le \bar{p}^{\mathrm{s}}$$

Power balance constraint:

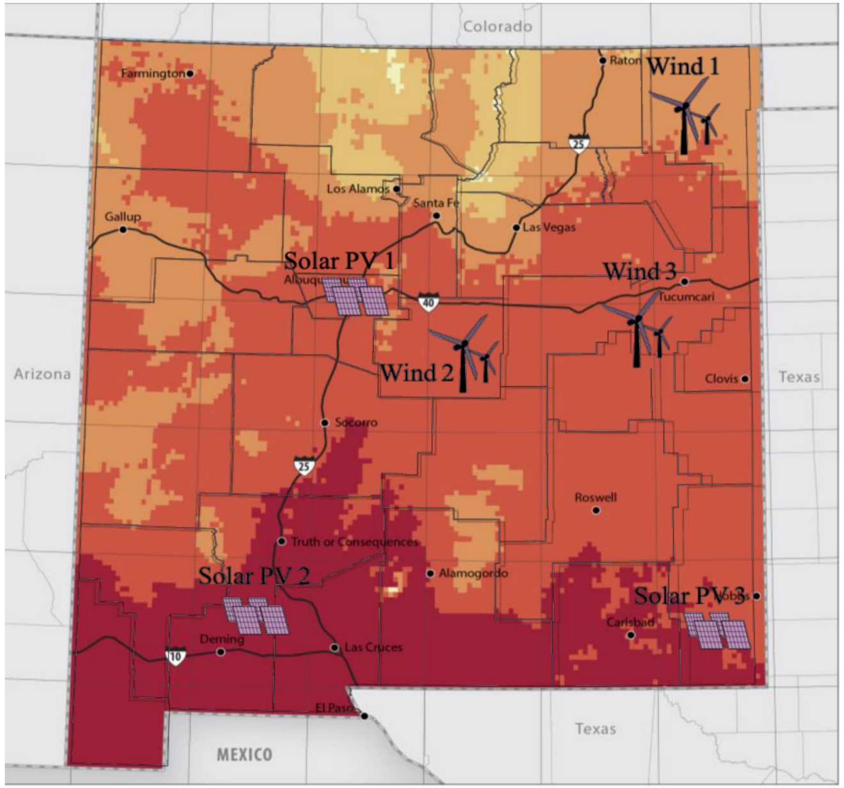
$$p_k^{\ell} = \sum_{i=1}^{n_{\mathrm{w}}} p_{k,i}^{\mathrm{w}} + \sum_{i=1}^{n_{\mathrm{pv}}} p_{k,i}^{\mathrm{pv}} + p_k^{\mathrm{d}} - p_k^{\mathrm{c}} - p_k^{\mathrm{curt}} + p_k^{\mathrm{trade}}$$

Curtailment and interconnection constraints:

$$0 \le p_k^{\mathrm{curt}} \le \bar{p}_k^{\mathrm{curt}}$$

$$\underline{p}_k^{\mathrm{trade}} \le p_k^{\mathrm{trade}} \le \bar{p}_k^{\mathrm{trade}}$$

CASE STUDIES – NEW MEXICO



New Mexico Solar Resource

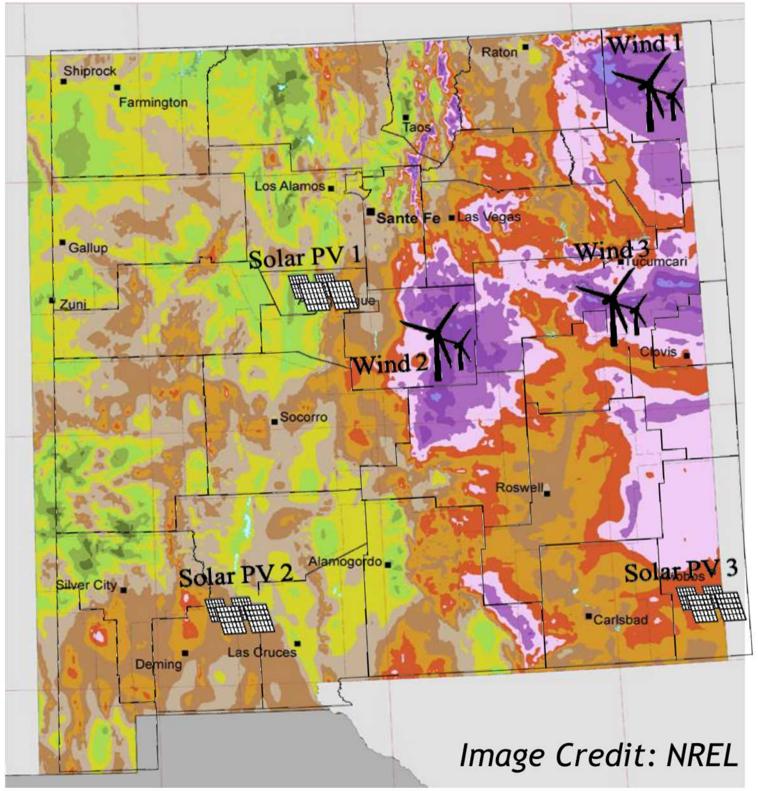


Image Credit: NREL

New Mexico Wind Resource

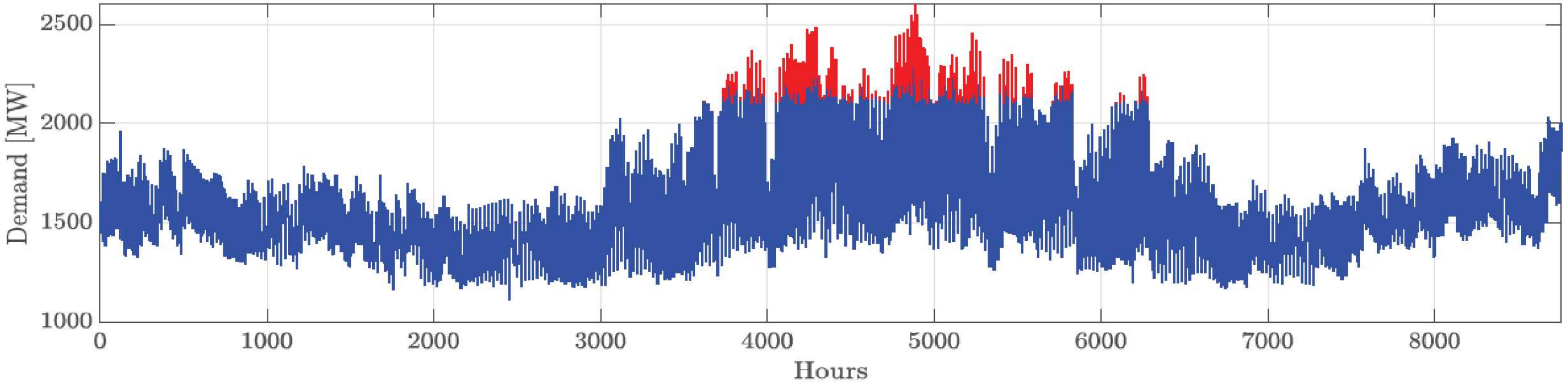


Table 2: Cases

Case	Description
1	2018 demand data and TMY weather data.
2	2017 demand and weather data.
3	2016 demand and weather data.
4	Case 1 with only solar PV resources.
5	Case 1 with only wind resources.
Subcase	Trade allowed when:
x.1	Never
x.2	Any hour
x.3	$p_k^\ell > 1600$ MW
x.4	$p_k^\ell > 1700$ MW
x.5	$p_k^\ell > 1800$ MW
x.6	$p_k^\ell > 1900$ MW
x.7	$p_k^\ell > 2000$ MW
x.8	$p_k^\ell > 2100$ MW
x.9	$p_k^\ell > 2200$ MW

Table 3: Model Parameters

Parameter	Description	Value	Units
η^s	ES self-discharge efficiency	1.00	-
η^c	ES roundtrip efficiency	0.85	-
η^{pv}	PV panel efficiency	0.15	-
η^{conv}	PV conversion efficiency	0.90	-
$\underline{v}$	Wind turbine cut-in speed	4	m/s
v^*	Wind turbine rated speed	10	m/s
$\overline{v}$	Wind turbine cut-out speed	25	m/s
h	Wind turbine hub height	80	m
a^{turb}	Wind turbine rotor area	5027	m^2
$\overline{p}^{turb}$	Wind turbine power rating	2	MW
ρ	Air density	1.2	kg/m^3

Table 4: Optimization Parameters

Parameter	Description	Value	Units
τ	Time-step	1	hours
K	Optimization horizon	8760	hours
w^s	Weight on ES energy capacity	1	-
w^p	Weight on ES power rating	0.5	-
w^w	Weight on wind power rating	1	-
w^{pv}	Weight on PV power rating	1	-
w_k^{curt}	Weight on curtailed power	$0\ \forall k$	-
w_k^{trade}	Weight on external power	$0\ \forall k$	-
δ	Fraction of unused SoE	0	-
γ	Fraction of initial/final SoE	0.5	-
$\overline{p}_k^{curt}$	Curtailed power allowed	$p_k^{pv} + p_k^{w}$	MW
$\underline{p}_k^{trade}$	Import power allowed	$500\ \forall k$	MW
$\overline{p}_k^{trade}$	Export power allowed	$-500\ \forall k$	MW

CASE STUDIES – NEW MEXICO - RESULTS

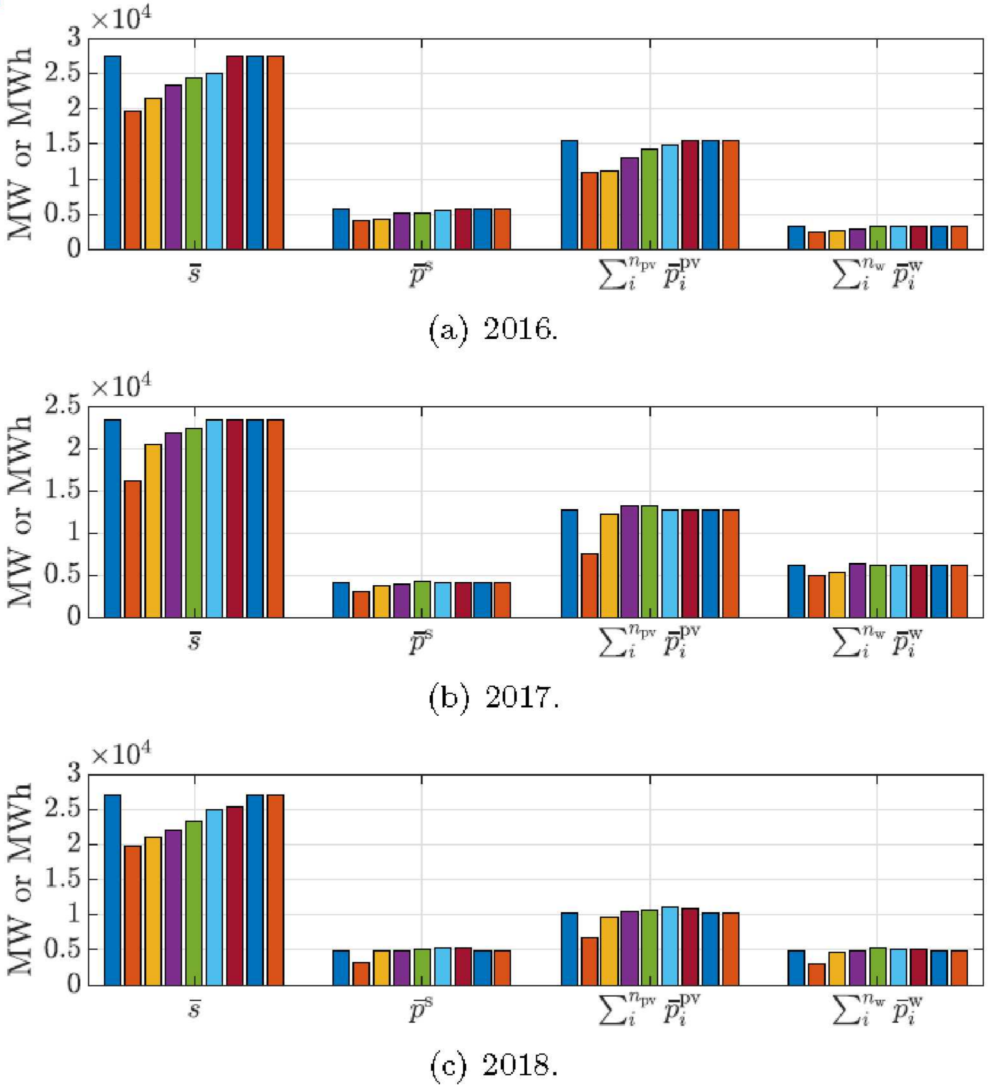


Figure 6: Summary of results for Cases 1-3. Each bar corresponds to a different subcase 1-9 going from left to right, respectively.

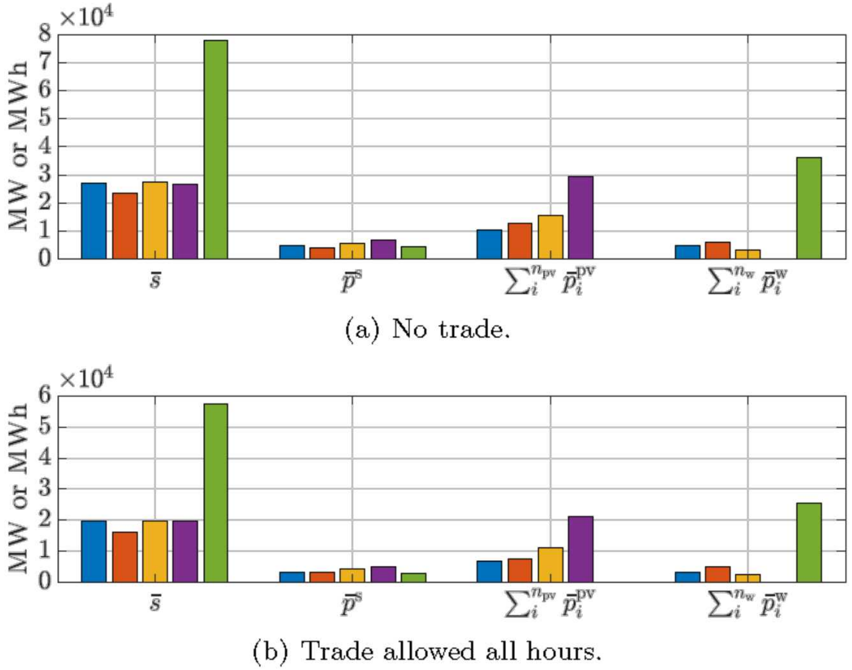


Figure 7: Summary of results for Cases 1-5 corresponding to no trading allowed (subcase 1) or trading allowed any hour (subcase 2). The bars correspond to Cases 1, 2, 3, 4, and 5 (from left to right).

Table 6: Land area for renewable resources (in thousands of acres)

	Solar PV		Wind	
Case	No trade	Trade any hour	No trade	Trade any hour
1	325.6	214.2	408.9	262.1
2	402.5	235.9	522.9	418.8
3	488.2	347.3	286.7	204.9
4	927.1	662.9	0	0
5	0	0	3034.3	2149.8

CASE STUDIES – NEW MEXICO - RESULTS

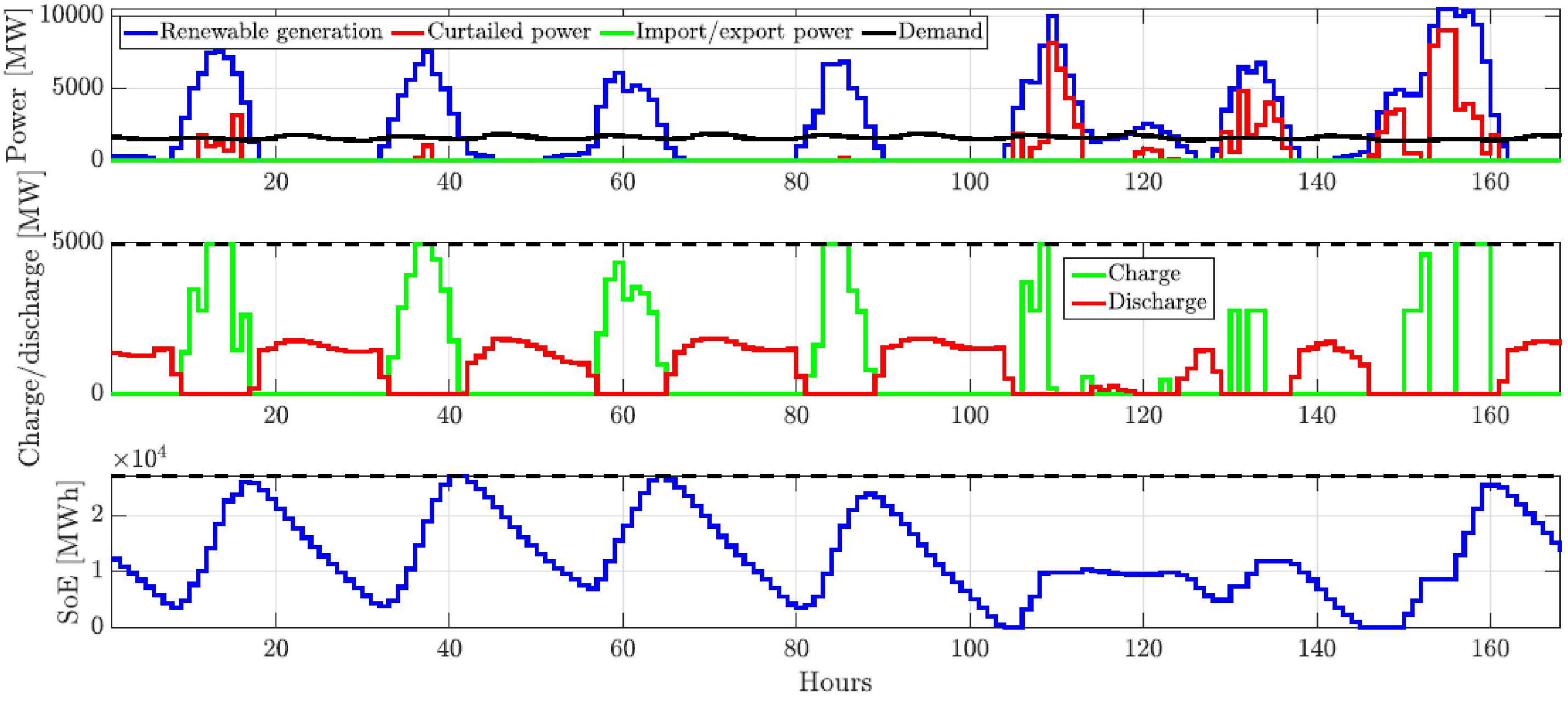


Figure 4: Results for the first week in January for Case 1.9. Renewable generation, curtailment, import power, and demand are show in the top subplot. ES charge and discharge are shown in the middle subplot, and ES SoE is shown in the bottom subplot.

CASE STUDIES – NEW MEXICO - RESULTS

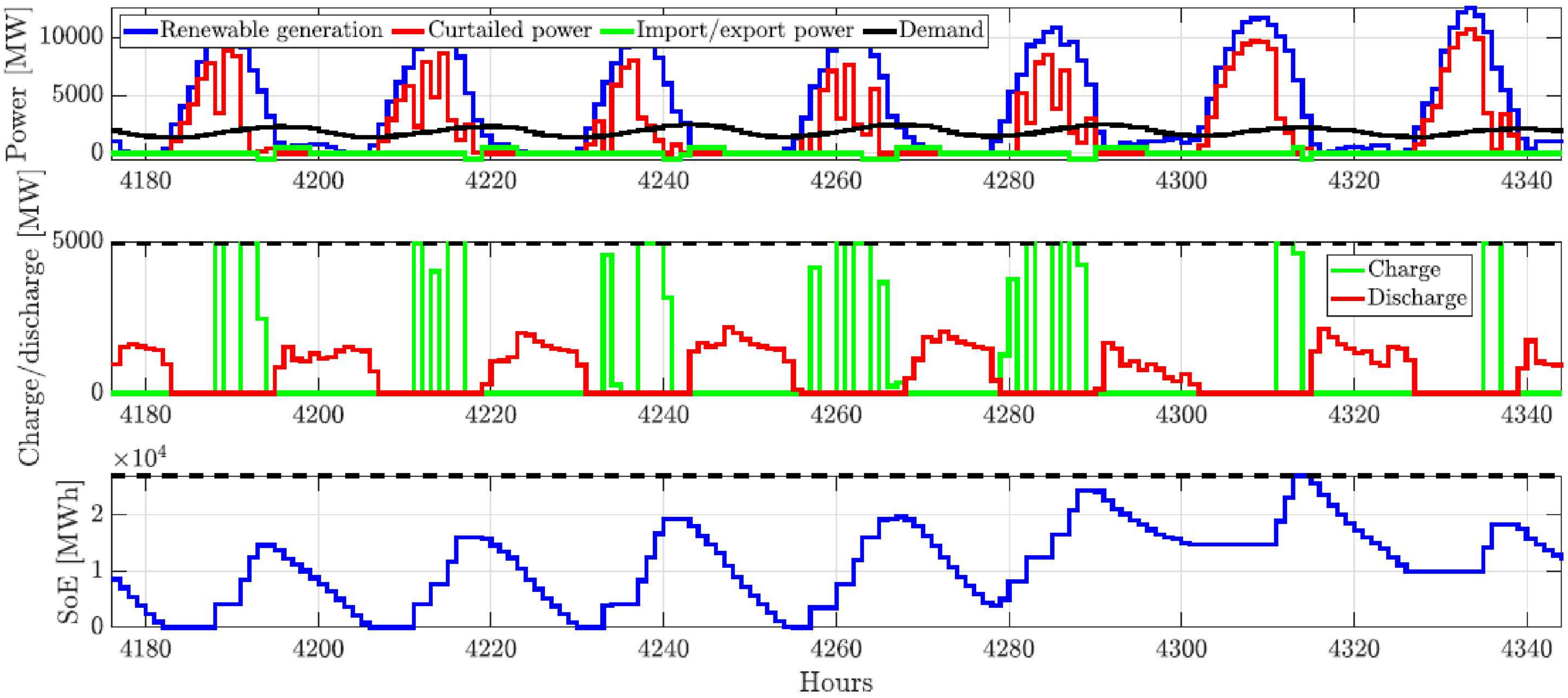


Figure 5: Results for the last week in June for Case 1.9. Renewable generation, curtailment, import power, and demand are show in the top subplot. ES charge and discharge are shown in the middle subplot, and ES SoE is shown in the bottom subplot.

CASE STUDIES – NEW MEXICO – KEY FINDINGS

- For 100% renewable, the resources required are roughly 5 GW / 25 GWh of energy storage, more than 10 GW of solar PV, and about 5 GW of wind.
- Considering only wind generation nearly triples the required storage energy capacity and requires the largest renewable power rating.
- The area of land required for the renewable generation plants is on the order of 1 million acres, or about 1% of the area of New Mexico.
- Energy trading can significantly reduce the size of required resources.
- If renewable generation resources are sized to meet about 80% of the peak demand, they are also large enough to meet 100% of the demand. Thus, peaker plants are no longer required.
- A significant amount of the generation must be curtailed to reduce energy storage size

CONCLUSIONS AND FUTURE WORK

- This work provides essentially a lower bound on the size of required resources to meet 100% of a utility's demand with renewable generation using a retrospective analysis.

- In future work, transmission system models will also be considered to ensure feasibility of the locations and sizes of the generation resources.

- In addition, a stochastic approach that takes into account future forecasts of demand and generation will be incorporated to address operational considerations that utilities will need to be prepared for in the future.

RELATED WORK

1. Byrne, R. H., Nguyen, T. A., Copp, D. A., Chalamala, B. R., & Gyuk, I, "Energy Management and Optimization Methods for Grid Energy Storage Systems," in IEEE Access, vol. 6, pp. 13231-13260, 2018.
2. T. A. Nguyen, D. A. Copp, R. H. Byrne, B. R. Chalamala, "Market Evaluation of Energy Storage Systems Incorporating Technology-specific Nonlinear Models," in IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 3706 – 3715, April 2019.
3. T. A. Nguyen, D. A. Copp, R. H. Byrne, "Stacking Revenue of Energy Storage System from Resilience, T&D Deferral and Arbitrage," accepted for the 2019 IEEE Power and Energy Society General Meeting, Aug 2019, Atlanta, GA.
4. R. Concepcion, F. Wilches-Bernal, R. H. Byrne, "Revenue Opportunities for Electric Storage Resources in the Southwest Power Pool Integrated Marketplace," accepted for the 2019 IEEE Power and Energy Society General Meeting, Aug 2019, Atlanta, GA.
5. F. Wilches-Bernal, R. Concepcion, R. H. Byrne, "Participation of Electric Storage Resources in the NYISO Electricity and Frequency Regulation Markets," accepted for the 2019 IEEE Power and Energy Society General Meeting, Aug 2019, Atlanta, GA.
6. D. A. Copp, T. A. Nguyen, and R. H. Byrne, "Adaptive Model Predictive Control for Real-time Dispatch of Energy Storage systems," accepted for the 2019 IEEE American Control Conference, Jul 2019, Philadelphia, PA.
7. A. Ingalalli, A. Luna, V. Durvasulu, T. Hansen, R. Tonkoski, D. A. Copp, T. A. Nguyen, "Energy Storage Systems in Emerging Electricity Markets: Frequency Regulation and Resiliency," accepted the 2019 IEEE Power and Energy Society General Meeting, Aug 2019, Atlanta, GA.
8. T. A. Nguyen and R. H. Byrne, "Optimal Time-of-Use Management with Power Factor Correction Using Behind-the-Meter Energy Storage Systems," in the proceedings of the 2018 IEEE Power and Energy Society General Meeting, Aug 2018, Portland, OR. (Selected for Best Paper Session in Power System Planning, Operation, and Electricity Markets.)
9. T. A. Nguyen, R. Rigo-Mariani, M. Ortega-Vazquez, D.S. Kirschen, "Voltage Regulation in Distribution Grid Using PV Smart Inverters," in the proceedings of the 2018 IEEE Power and Energy Society General Meeting, Aug 2018, Portland, OR.
10. R. H. Byrne and T. A. Nguyen, "Opportunities for Energy Storage in CAISO," in the proceedings of the 2018 IEEE Power and Energy Society General Meeting, Aug 2018, Portland, OR.
11. D. A. Copp, T. A. Nguyen and R. H. Byrne, "Optimal Sizing of Behind-the-Meter Energy Storage with Stochastic Load and PV Generation for Islanded Operation," in the proceedings of the 2018 IEEE Power and Energy Society General Meeting, Aug 2018, Portland, OR.
12. T. A. Nguyen, R. H. Byrne, B. R. Chalamala and I. Gyuk, "Maximizing The Revenue of Energy Storage Systems in Market Areas Considering Nonlinear Storage Efficiencies," in the proceedings of the 2018 IEEE Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM 2018), June 2018, Amalfi, Italy.
13. R. H. Byrne, T. A. Nguyen, D. A. Copp and I. Gyuk, "Opportunities for Energy Storage in CAISO: Day-Ahead and Real-Time Market Arbitrage," in the proceedings of the 2018 IEEE Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM 2018), June 2018, Amalfi, Italy.
14. Christoph Lackner, T. A. Nguyen, Raymond H. Byrne and Frank Wiegandt, "Energy Storage Participation in the German Secondary Regulation Market," in the proceedings of the 2018 IEEE Transmission and Distribution Conference and Exposition, Apr 2018, Denver, CO.
15. T. A. Nguyen, R. H. Byrne, R. Concepcion, and I. Gyuk, "Maximizing Revenue from Electrical Energy Storage in MISO Energy & Frequency Regulation Markets," in Proceedings of the 2017 IEEE Power Energy Society General Meeting, Chicago, IL, July 2017, pp. 1–5.
16. T. A. Nguyen and R. H. Byrne, " Maximizing the Cost-savings for Time-of-use and Net-metering Customers Using Behind-the-meter Energy Storage Systems," in Proceedings of the 2017 North American Power Symposium, Morgan Town, WV, 2017, pp. 1-7.
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